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RECOMMENDED *DE MINIMIS* RADIATION DOSE RATES FOR CANADA

by the

Advisory Committee on
Radiological Protection
and the
Advisory Committee on
Nuclear Safety

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ABSTRACT

A *de minimis* dose or dose rate as used in this report represents a level of risk which is generally accepted as being of no significance to an individual, or in the case of a population, of no significance to society. The doses corresponding to these levels of risk are based on current scientific knowledge. Dose rates recommended in this report are as follows:

- a *de minimis* individual dose rate of 10 μSv a^{-1}, based on a risk level that would generally be regarded as negligible in comparison with other risks, and
- a *de minimis* collective dose rate of 1 person-Sv a^{-1}, based on an imperceptible increase above the normal incidences of cancer and genetic defects in the exposed population.

The concept of *de minimis* is to be distinguished from "exempt from regulation" (below regulatory concern). The latter involves broader social and economic factors which encompass but are not limited to the purely risk-based factors addressed by the *de minimis* dose. *De minimis* is one of the factors that determine the exemption of sources or practices that may result in doses below or above the *de minimis* level.

Although these *de minimis* dose rates should be considered in developing criteria and guidelines for deriving quantities and concentrations of radioactive substances that may be exempted from regulation, this document is only concerned with establishing *de minimis* dose rates, not with exempting sources and practices.

RECOMMENDED *DE MINIMIS* RADIATION DOSE RATES FOR CANADA

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PREFACE:

The AECB's Advisory Committee on Radiological Protection (ACRP) and Advisory Committee on Nuclear Safety (ACNS) have reviewed the scientific literature on the concepts of *de minimis*. They herein recommend that the AECB adopt both individual and collective *de minimis* dose rates as two of the criteria for exempting certain sources of radiation from regulatory control. The considerations leading to this recommendation are the subject of this report.

This report was originally approved for publication by the AECB in February, 1988, and was subsequently revised in April 1990 in the light of more recent information.

RECOMMENDED *DE MINIMIS* RADIATION DOSE RATES FOR CANADA

1. SCOPE OF REPORT

This report addresses primarily the establishment of *de minimis* dose* rates, both individual and collective. In order to apply these dose rates to the exemption of practices or sources from regulatory controls other factors such as the justification of the practice and probability of exposure from multiple sources must be taken into account. In addition, these dose rates must be translated into equivalent quantities and concentrations of specific radioactive substances, taking into account the pathways and the biological factors affecting the doses received by individuals and populations. Such translation of *de minimis* dose rates into quantities and concentrations of radioactive substances that may be exempted from regulation is not addressed in this report.

2. INTRODUCTION

A primary objective of the Atomic Energy Control Board (AECB), in its administration of the Atomic Energy Control Act and the Regulations made under it (AE85a, 88), is to ensure that the risk from the activities it regulates is appropriately low. This is not stated in the Act or Regulations but is implicit in the conditions included in licences in the interests of health, safety, and security. In many situations, however, the actual and potential radiation dose rates and resulting health risks are so small that efforts to control the sources of such dose rates would constitute an undue expenditure of societal resources for an insignificant benefit in health protection. Such low dose rates have been termed "*de minimis*", from the Latin legal phrase, "*de minimis non curat lex*", which can be freely translated as "the law does not concern itself with trifles".

The health risk associated with a *de minimis* dose rate is generally accepted to be trivial in comparison with other risks which are experienced by individuals. In fact, the regulations do include provisions for exempting certain sources of radiation from regulation, and various other exemptions are made implicitly or explicitly in the licensing process. Recognizing that some exemption levels will continue to be based on practical considerations (as with minimum recording levels for internal and external dosimetry, for example) it is nevertheless desirable to develop a basic rationale for *de minimis* individual and collective dose rates to assist in making the decision to exempt a source or practice from regulatory control.

2.1 Risk of Biological Effects from Radiation

The deleterious effects of large doses of ionizing radiation are well-documented. Doses of a few sieverts** can be fatal within hours or weeks. At doses of the order of 100 mSv or less, there are no early effects, but a small chance of eventually developing cancer is inferred from statistical excesses of cancer

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* "Dose" in this report means "effective dose equivalent" ("EDE") unless otherwise specified, and includes the "committed dose" from radioactive substances in the body.

** The basic unit of "dose" is the "sievert" (Sv). The submultiples "millisievert" (mSv) and "microsievert" (μSv) are also used in this report.

observed amongst large populations which have received large doses at high dose rates. In addition to the possibility of cancer, research on mammals suggests that irradiation of the gonads can also lead to inherited defects in humans (UN77,82,86).

The risk of delayed harmful effects from very small doses is rather uncertain. Any harmful effects resulting from doses within the range of the normal annual variation of dose from background radiation would be so infrequent as to be indistinguishable from the normal incidence of cancer and genetic defects. While there is not complete agreement concerning the exact dose-response relationship, it is assumed for purposes of radiation protection that the effect is linearly proportional to the dose down to zero dose. The assumption follows that equal increments of dose make equal additions to the probability of an effect, even for very small doses. This may, especially for radiation of low linear rate of energy transfer ("low-LET"), add a degree of conservatism to the risk estimates for low doses.

The risk factors for fatal cancers and serious genetic defects from BEIR, ICRP and UNSCEAR are listed in Table 1. These are derived from data at high doses and high dose rates and some reduction factor may be appropriate for doses at low dose rates. UNSCEAR has suggested dose reduction factors in the range of 2-10 (UN88). BEIR V has suggested dose reduction factors of 3-4 for all cancers except leukemia for which there is already an implicit reduction factor of 2 in their report (BE90). The latest ICRP report gives a dose rate and dose rate effectiveness factor of 2 (IC90). In this report we have therefore chosen to use a range of risk factors for subsequent calculations: 1×10^{-2} to 10×10^{-2} per person-Sv, which allows for both fatal cancers and serious genetic effects and includes an allowance for dose and dose rate reduction factors.

2.2 Radiation Protection Principles

Three basic principles of radiation protection have been recommended by the ICRP (IC77a), which are widely accepted:

(1) no practice shall be adopted unless its introduction produces a positive net benefit,

(2) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account (ALARA), and

(3) the dose to individuals shall not exceed the specified limits.

These principles can also be expressed as justification of practices, optimization of radiation protection, and limitation of individual doses. The Advisory Committee on Nuclear Safety included these principles in its safety objectives for nuclear activities (AC81), which were subsequently endorsed by the AECB.

Thus, a practice that results only in *de minimis* doses of radiation is not necessarily justified. It could be unjustified for reasons that are unrelated to radiation, but such considerations are beyond the scope of this report.

Application of the ALARA or optimization principle requires an assessment which may be a cost-benefit or equivalent evaluation to determine if the individual or collective doses from any particular practice can be reduced at a reasonable cost. ALARA considerations have been used by others in arriving at *de minimis* dose values, as discussed in 3.3.

Individual dose limits are specified in the Atomic Energy Control Regulations, and are summarized in Table 2. These limits, which basically follow the recommendations of the ICRP, apply to regulated activities and are therefore much higher than any doses derived from *de minimis* criteria.

2.3 Radiation from Natural and Man-Made Sources

A knowledge of radiation exposures and their variation provides some perspective against which the significance of *de minimis* dose rates can be judged. Everyone is exposed to natural background radiation, the major sources of which are external exposure from cosmic radiation and from radioactive substances in the earth, and internal exposure from naturally-occurring radioactive substances taken into the body with food, water and air. In addition, most people are exposed to man-made sources, the most important of which are medical procedures employing radiation.

The various sources of radiation are described below and summarized in Table 3, the major natural sources in (a) and (b), and medical irradiation in (c). Radiation from the nuclear fuel cycle is also included for completeness, in (d), although its contribution is relatively minor.

The dose from natural sources varies widely from place to place. Estimates of the average doses vary from 2400-3000 $\mu Sv\ a^{-1}$. Man-made sources can contribute doses up to 2100 $\mu Sv\ a^{-1}$ in industrialized countries, most of which come from medical irradiation, with estimated exposures per person of 400-2000 $\mu Sv\ a^{-1}$. One chest x-ray for example delivers a dose of 70-80 μSv.

(a) External Dose Rates

External sources of natural background radiation include gamma radiation from radioactive materials in the soil and rocks and cosmic radiation. External dose rates measured by the Bureau of Radiation and Medical Devices of Health and Welfare Canada using thermoluminescence dosimeters are summarized in Table 4. The smallest annual dose in a major Canadian population centre was 400 $\mu Sv\ a^{-1}$. The annual population-weighted dose rate for Canada was about 470 $\mu Sv \pm 100\ a^{-1}$. A comprehensive survey has also been made by the Geological Survey of Canada, which showed cross-Canada average dose rates of 170 $\pm$ 100 $\mu Sv\ a^{-1}$ from the soil and 320 $\pm$ 30 $\mu Sv\ a^{-1}$ from cosmic radiation, for a total of 490 $\pm$ 100 $\mu Sv\ a^{-1}$ (GR84), which is in good agreement with the BRMD data.

It would appear from these data that the minimum unavoidable external dose rate in Canadian cities is about 400 $\mu Sv\ a^{-1}$, with considerably higher dose rates (up to about 640 $\mu Sv\ a^{-1}$) in some locations. The differences are mostly due to differ-ences in terrestrial radiation.

A comprehensive review of exposure to natural background radiation for Canada and the United States has been carried out by the National Council on Radiation Protection and Measurements (NC87). According to this review the annual average

exposure to cosmic radiation is 270 $\mu Sv\ a^{-1}$ with a range of 150-5000 $\mu Sv\ a^{-1}$ depending on the amount and type of aircraft travel. Exposure to terrestrial radiation was estimated to be 280 $\mu Sv\ a^{-1}$ with a range of 160-630 $\mu Sv\ a^{-1}$.

(b) Internal Dose Rates

The major naturally occurring sources of internal radiation are potassium-40 taken into the body in food, and inhaled radon progeny. The average effective dose equivalent from potassium-40 is about 190 $\mu Sv\ a^{-1}$. The total dose due to radionuclides incorporated in the body has been estimated to be 390 $\mu Sv\ a^{-1}$ (NC87c).

Radon progeny measurements in Canadian homes are summarized in Table 5. The average exposures vary by more than a factor of ten from city to city, with even greater variations from house to house. The average effective dose equivalent received by Canadians from inhaled radon progeny is about 600 $\mu Sv\ a^{-1}$. The NCRP has estimated the average dose from inhalation of radon progeny to be about 2000 $\mu Sv\ a^{-1}$ in the U.S. (NC87c).

(c) Medical Irradiation

The average annual dose of radiation received from medical procedures has been estimated by UNSCEAR and BEIR to be 400-1000 $\mu Sv\ a^{-1}$ (UN88, NC89). This may be an overestimate of the effective dose equivalent since some of the dose values included in the average relate to parts of the body only. On the other hand, a recent review suggests that the effective dose equivalent from medical exposures in Canada may amount to 2000 $\mu Sv\ a^{-1}$, averaged over the Canadian population, including about 20 $\mu Sv\ a^{-1}$ from radiopharmaceuticals (Le88). Not included are doses from fluoroscopy, interventional radiology, and radiation cancer therapy.

(d) Radiation From the Nuclear Fuel Cycle

The nuclear fuel cycle includes all the activities from the mining of uranium to the production of electricity, as well as reactor decommissioning and waste management. The dose rates resulting from normal operations are usually only measurable close to the facilities, if at all. The dose rates to people at greater distances are too small to be measured and can only be estimated by calculation from measured release rates.

The calculated maximum dose rate to any member of the public in the neighborhood of Canadian nuclear power stations is about 50 $\mu Sv\ a^{-1}$ (OH88). Uranium dust released from uranium refineries has been estimated to result in doses as high as 200 $\mu Sv\ a^{-1}$ to the most highly exposed members of the public (Tr86). In addition, Canadians receive a small dose from nuclear fuel cycle operations in other countries, which is estimated by UNSCEAR to have been 0.1 $\mu Sv\ a^{-1}$ in 1980 and to increase to 1 $\mu Sv\ a^{-1}$ by the year 2000 (UN82).

2.4 Normal Incidences of Cancer and Genetic Defects

The significance of the risks of radiation-induced cancer and genetic defects associated with a *de minimis* dose can be judged by comparison with the normal incidence of these diseases, which varies widely depending on factors such as age, sex and location. For example, as indicated in Table 6, the cancer death

rate in Canada increases with age, especially after about age 45. The death rate is less than 1 in 1000 per year below age 45, but increases to 18 in 1000 per year amongst persons 85 and older. Variations with sex and province are also indicated in Table 6.

A reference value for the normal incidence of cancer and genetic defects can be derived from the overall cancer death rate and the normal incidence of genetic defects. In 1985, 25.8% of deaths in Canada were due to cancer (SC85), and UNSCEAR has reported that about 6% of live-born children suffer some serious disability of genetic origin (UN77, UN86). Combining these values and rounding off gives a reference value of 30%. That is, it is assumed for purposes of this report that about 30% of Canadians normally die of cancer or suffer some serious ailment of genetic origin.

3. INITIATIVES BY OTHERS WITH RESPECT TO *DE MINIMIS* AND EXEMPTION FROM REGULATION

Wide interest in *de minimis* doses and exemption from regulation exists within radiation protection circles throughout the world. Initially, much of this interest related to waste management or waste disposal, and in particular with a desire to determine levels of radioactive waste that may be exempted from licensing. More recently, attention has been directed to generic criteria for exemption of sources and practices from regulatory control. Terms found in the literature include *"de minimis"*, "below regulatory concern", "exempt from regulation", and "negligible individual risk level". Usage of the terms has not been consistent, and in some cases they have been used interchangeably.

An international consensus appears to be developing (US88b) that there are two separate concepts - *de minimis*, meaning a trivial level of risk or dose applied to individuals or populations, and "exempt from regulatory control", which applies to a source or a practice. *De minimis* may be one of the criteria entering into the decision to exempt a source or practice from regulation. The Advisory Committees support this approach and it is embodied in the recommendations of this report.

3.1 International Atomic Energy Agency (IAEA)

The IAEA stated in its Basic Safety Standards for Radiation Protection: "When reaching a decision about exempting sources of radiation or practices involving radiation exposure, the competent authority should be assured that the detriment connected with the use of sources or (carrying out) of practices will be so small as not to warrant the application of the system of notification, registration or licensing" (IA82). The principles for exemption from regulation were elaborated in a subsequent IAEA document in which were proposed *de minimis* dose rates of 10 $\mu Sv\ a^{-1}$ for the effective dose equivalent and 500 $\mu Sv/a$ for the dose to the skin (IA87). These values were supported by the observations that they are only 1% of the dose limits recommended by the ICRP for continuous exposure of members of the public (IC77a,85), and by the judgment that it is unlikely that the total dose received by any individual from several exempted sources would exceed about 10% of the dose limits. However, if a competent authority were to anticipate that the total dose from several exempted sources might exceed 10% of a dose limit, the IAEA suggested that this be taken into account when considering specific

exemptions. The IAEA also noted that 10 μSv a^{-1} is only about 0.5% of the dose rate from natural background radiation, and that it corresponds to a risk of fatal cancer or serious hereditary effects of the order of 10^{-7} per year.

A collective *de minimis* value was also proposed by the IAEA; namely, a dose commitment of 1 person-Sv per exempted source or practice (with acknowledged uncertainty as to what constitutes a source or practice in this context) (IA87). This value was supported by the rationale that it is low enough that the total collective dose from all exempted sources would not be excessive, and that there would be no potential for reducing the dose below the *de minimis* value at a reasonable cost (the same rationale as used in the NRPB approach outlined in 3.3 below). It was also noted that there would be a high probability of no deleterious effects at all in the exposed population.

The IAEA also stated: "Competent authorities may have reasons beyond the scope of this document for either exempting or not exempting particular sources or practices from regulatory control. For example, they may want to prohibit frivolous uses of radioactive materials even if the associated doses are trivial." (IA87)

In IAEA Safety Series No. 89 (IA88), two basic criteria are specified for determining whether or not a practice would be a candidate for exemption from regulatory control. These are:

(1) individual risks must be sufficiently low as not to warrant regulatory concern; and

(2) radiation protection, including the cost of regulatory control, must be optimized.

The first of these criteria is addressed by defining a trivial or *de minimis* level of individual dose. This level is set at a few tens of microsieverts per year based upon consideration of "acceptable" individual risk, and variations in the levels of natural background radiation. In applying this *de minimis* individual dose to exemption of a source or a practice, consideration is given to exposure from multiple sources, leading to a source-related exemption criterion of 10 microsieverts per year.

The second criterion, that of optimization, is addressed by considering the collective dose commitment per year of practice. Here, a level of 1 person-sievert per year of practice is recommended as the cutoff below which a formal optimization analysis need not be performed.

3.2 National Council on Radiation Protection and Measurements (NCRP, USA)

The NCRP has defined a "Negligible Individual Risk Level" ("NIRL") below which radiation protection efforts are unwarranted. The NIRL is 10 μSv a^{-1} from each source or practice (or up to 100 μSv a^{-1} in the unlikely event that a given person is exposed to as many as ten such sources in a given year). The basis of the 10 μSv a^{-1} value is that the associated risk of radiation-induced harm is very small (of the order of 10^{-7}/a) compared to the risk commonly accepted in other societal activities, that it is only 1% of the dose limit (IC77a, IC90) recommended for continuous exposure of members of the public, and that it is only about 1% of the natural background dose rate (excluding radon) (NC87c).

Ten μSv a^{-1} is also recommended as a value below which individual doses need not be considered when calculating collective doses, including the collective dose for use in ALARA calculations (NC87c).

3.3 National Radiological Protection Board (NRPB, UK)

The NRPB has recommended a *de minimis* individual dose rate of 5 μSv a^{-1}, which is 1/10 of the derived single-source dose rate to allow for potential exposure to multiple sources. Also recommended is a collective *de minimis* value of 1 person-Sv, which is to be applied to the dose commitment arising from the operating lifetime of a given radiation source. The 1 person-Sv value was derived from cost-benefit considerations, assuming that any such calculations would alone cost at least £2000 (NR85a, NR85b).

3.4 Nuclear Regulatory Commission (US)

The United States Nuclear Regulatory Commission has published its intent to develop a policy on exemptions from regulatory control for practices whose health and safety impacts could be considered below regulatory concern ((US88a). One of the proposed criteria for exemption from regulation is an annual individual dose level of 0.1 mSv or less. This level is not intended to represent a *de minimis* risk but rather a level of risk or dose below which it is unnecessary to perform any type of cost-benefit analysis (US88a, US88b).

The Commission has not established a collective dose limit, but has requested comments on the need for and the value of such a criterion.

4. *DE MINIMIS* DOSE AND THE AECB

The Atomic Energy Control Board (AECB) suggested a *de minimis* dose rate of 50 μSv a^{-1} as a criterion to be used in case-by-case consideration of the exemption from regulatory control of the disposal of certain contaminated materials (AE85b). Such materials could then be recycled or disposed of by conventional means. The basis of the 50 μSv a^{-1} value is that the associated radiological risk, of the order of one in a million per year, appears to be at the threshold of risks that are considered insignificant by individuals. This observation is supported by comparison with other risks and standards: 50 μSv a^{-1} is well within the range of doses from natural background radiation, and is 1% of the current Canadian regulatory dose limit of 5 mSv a^{-1} for the public.

With respect to collective dose, the AECB noted that the number of people exposed to *de minimis* sources should be limited in order to limit the overall impact of unregulated sources. Pending the development of more general criteria, the AECB proposed to restrict the application of its *de minimis* criterion to disposal practices for which the anticipated radiological impact is localized and for which the potential for exposure of large populations is small. Any reduction due to the exposure of a given group of people to several *de minimis* sources would be determined case by case when considering applications for exemption of particular disposal practices from licensing (AE85b,86).

5. IMPORTANCE OF COLLECTIVE DOSE

If the number of people receiving a *de minimis* dose is small, the collective dose will also be small and it is unlikely that any harmful effect at all will result. For example, if 1000 people were each to receive 10 μSv per year, the collective dose would be 0.01 person-Sv/a (in addition to the approximately 3 person-Sv/a they would receive from natural background radiation). For a range of risk coefficients of 1 to 10 x 10^{-2} per person-Sv, the chance of additional fatal cancers or serious genetic defects would be 0.1 to 1 in 1000 per year. In other words, if 1000 people in each successive generation each received 10 μSv a^{-1}, the expected result would be 0.1 to 1 additional fatal cancer or serious genetic defect to occur once every 1000 years. Many would consider such risks to be negligible in comparison to other every-day risks. Sources giving rise to such small doses to a small population could therefore be considered to be of negligible concern from both the individual and collective points of view.

On the other hand, if a larger number of people were each to receive a *de minimis* dose, due to dispersal of a source in the environment for example, the resulting collective dose might be too large to be considered negligible from a collective (or societal) point of view. For example, if one million people were each to receive 10 μSv per year, the collective dose would be 10 person-Sv per year. For a risk range of 1 to 10 x 10^{-2} per person-Sv, the estimated number of fatal cancers and genetic defects amongst the one million people would be in the range of 7.5 to 75 in a 75-year lifetime, or 0.1 to 1 per year on average.

These calculated effects would be indistinguishable from the many more cancers and genetic defects that would occur in the same population due to natural and other causes (which are discussed in 2.4). It would therefore be impossible to demonstrate whether or not the calculated effects would actually occur. However, if such a finite number of radiation-induced effects is calculated, it is prudent to assume for radiation protection purposes that the effects will actually occur. The number of such estimated effects (7.5 to 75 in the above example) might be of concern from a collective or societal point of view even though the radiation risk to each exposed individual is negligible. In other words, some collective concern might be warranted even if all individual doses are at a *de minimis* level. Therefore, a *de minimis* collective dose criterion may be needed in addition to the *de minimis* individual dose criterion.

There is no consensus world-wide on the need for a *de minimis* collective dose criterion. As mentioned above, some organizations have recommended collective *de minimis* doses or *de minimis*-based cut-offs for calculating collective doses. While the USNRC has requested comments on the need for and value of such a criterion, others have argued that, with an individual *de minimis* criterion, there is no need for a collective *de minimis* dose or dose rate (BO89, TA89).

However, the Advisory Committees believe that a collective *de minimis* dose criterion would be useful for the following reasons:

(i) it would draw attention to the collective risk associated with sources that give *de minimis* individual doses;

(ii) it would preclude the possibility of deliberate dilution and dispersion of large quantities of radioactive wastes, solely for the purpose of meeting the individual *de minimis* criterion. (Although dilution and dispersion of small quantities of radioactive material may sometimes be appropriate, large quantities of concentrated waste should generally be isolated rather than dispersed in the environment.)

iii) it would be useful when considering the possible regulation of certain long-lived and other radionuclides which can result in large dose commitments by delivering minute doses to a large number of people over a very long time. This is discussed further in section 6, below.

6. IMPORTANCE OF DOSE RATE

The health risk associated with a given source of radiation may be estimated by multiplying the calculated dose commitment by the radiation risk factor. However, in the case of long-lived radioactive substances dispersed in the environment, the dose commitment may be made up of minute doses received by successive generations of people over thousands or millions of years. The use of dose commitment in such circumstances is of questionable value because of the great uncertainty in estimating doses received in the distant future. The validity of estimating minuscule doses to be received far in the future is also questionable.

An alternative is to consider the dose received in a relatively short period of time. One year is generally an appropriate period for regulatory purposes, whereas the radiation dose accumulated over a lifetime is of interest to the persons exposed. Advantages of basing *de minimis* criteria on such annual dose rates and lifetime doses include the following:

(i) annual dose rates and lifetime doses can be calculated with much greater confidence than can the complete dose commitment for long-lived substances dispersed in the environment; and

(ii) the significance of annual dose rates and lifetime doses can be judged by comparison with more familiar risks:

- the dose accumulated in a year can be compared with the annual dose from background radiation from natural and other sources, and

- the dose accumulated in a lifetime can be assessed by comparing the resulting health detriment with the normal incidence of the same kinds of health effects that occur naturally or due to other causes.

7. ASSIGNING VALUES TO THE *DE MINIMIS* DOSE RATES

7.1 Criteria

Taking into account the initiatives by others (sections 3 and 4), and the importance of collective dose and of dose rate (sections 5 and 6), the Advisory Committees suggest the following criteria for setting *de minimis* dose rates:

- for the individual criterion, the risk of fatal cancer and serious genetic defects should be small enough to be negligible in comparison to other risks, and

- for the collective criterion, the risk of fatal cancer and serious genetic defects should be no greater than a small fraction of the normal risk of these diseases due to natural and other causes.

The determination of what is negligible is, to a large extent, dependent on an individual's perceptions. Several investigators (AC86, Fi77, RS83, S179, UT82, Wi79) have concluded that whether or not an individual considers a risk to his or another's life as negligible depends on factors such as:

- one's perception of the nature and magnitude of the risk compared to other risks,
- whether the risk occurs naturally or is man-made,
- how commonly it occurs and how well it is understood,
- whether it is voluntary or imposed, and
- its justification in terms of perceived benefits.

These investigators have also shown that the individual perception of a risk is greatly affected by the nature of the consequences; for example, a catastrophe such as a major aircraft crash is more dreaded than commonly occurring events such as automobile accidents, even though many more people are killed each year in car accidents than in aircraft crashes. They also note that nuclear activities are generally perceived by members of the public as presenting greater risks than have been estimated by experts.

It appears that most members of the public are not concerned about background radiation and its regional variation, except possibly in the case of exposure to radon in homes, which contributes approximately 2/3 of the average total exposure from background radiation. The external radiation exposures of 470 $\pm$ 100 μSv a^{-1} (see 2.3(a) above) in Canada contribute approximately 1/5 of the overall background dose. Apparent acceptance of this variation is most likely due to most of the public being unaware of the variation and its associated risks, and having more compelling reasons for choosing where to live. In any case 100 μSv a^{-1} is a starting point for de minimis doses which may be acceptable in terms of public perception.

Values are recommended below for individual (7.2) and collective (7.3) *de minimis* dose rates. Additional consideration may be required when applying these *de minimis* dose rates to the exemption of specific sources if a given group of people is exposed to several *de minimis* sources at the same time. Such considerations constitute regulatory issues and are outside the scope of this report.

7.2 Individual *De Minimis* Dose Rate

Given the subjective factors, it is difficult to select a risk value that everyone would ignore or would not be concerned about. However, several of the investigators have observed that, when an activity leads to an individual risk of

fatality less than 10^{-5} or 10^{-6}, that risk is generally ignored by most people. In order to provide additional perspective, some activities that have been calculated to increase one's chance of death by one in a million (10^{-6}) are listed in Table 7.

Figure 1 shows the relationship between annual dose rate and annual risk for overall risk coefficients covering a range of 1 to 10 x 10^{-2} per person-Sv (2.1), and illustrates the relatively small variation in dose rate corresponding to a given risk over the relatively wide range of risk coefficients considered in this report.

Recommended Value for the Individual *De Minimis* Dose Rate

The *de minimis* value recommended in this report is 10 μSv per year, which is associated with a risk of less than one in a million per year. This value is less than the variation from city to city in Canada of the natural background radiation from external sources (2.3.a and Table 4), and is much less than the variation in radiation dose from inhaled radon daughters in homes (2.3.b and Table 5).

In summary, a risk of the order of one in a million or less is generally of little or no concern. From Figure 1, a dose rate of 10 μSv a^{-1} is associated with an annual risk ranging from about 10^{-7} to 10^{-6} over the span of risk coefficients cited earlier. If a person were to receive 10 μSv every year, the total risk during a 75-year lifetime would be in the range of 0.0025% to 0.025% of the normal expectation of these adverse effects. Since such risk levels are generally not considered to be of concern by most individuals, nor by national and international health authorities, it would appear that a dose rate of 10 μSv a^{-1} would also be of no concern. The same could of course be said for any smaller dose rate, and also for somewhat larger dose rates. The choice of a specific *de minimis* value is therefore a matter of informed judgment, taking into account society's attitudes to other types of risk.

7.3 Collective *De Minimis* Dose Rate

As proposed in 7.1, the value chosen for the *de minimis* collective dose rate is to be such that the associated collective risk of radiation-induced cancer and genetic defects is only a small fraction of the normal expectation of these diseases in the population receiving the *de minimis* doses. How small this fraction should be is a matter of judgment. A source of radiation is likely to be of general concern if it is estimated to increase the incidence of cancer and genetic defects by more than about 1% of the normal incidence of these diseases, and some people might be concerned about an estimated increase as low as 0.1%. The concern would likely diminish to a level that could be considered *de minimis* as the estimated incidence of radiation-induced cancer and genetic injury decreased below 0.1% of the normal incidence.

In order to determine a value of collective dose rate that corresponds to 0.1% of the normal incidence of fatal cancer and serious genetic defects, it is necessary to know the number of such effects that normally occur in the population that may be exposed to radiation from a *de minimis* source. The collective risk per person-Sv, as well as the normal expectation of cancer and genetic defects, are calculated below.

(a) Collective Risk Due to Lifetime Exposure to Radiation

The risk of fatal cancer and serious genetic defects due to radiation lies in the range of 1 to 10 x 10^{-2} per person-Sv (2.1). If a population is exposed during each year of an average lifespan of 75 years, the lifetime expectation of fatal cancers and serious genetic defects due to the radiation is between 0.75 and 7.5 per person-Sv of annual collective dose for the range of risk coefficients considered here. (This value depends only on the collective dose, regardless of the number of people exposed.)

(b) Normal Expectation of Cancer and Genetic Defects

Of interest here is the number of people amongst those exposed to a given *de minimis* source who would normally (in the absence of the *de minimis* source) be expected to die of cancer or suffer a serious genetic defect. First, it is necessary to estimate the size of the exposed population: if every exposed person received the full *de minimis* amount of 10 μSv a^{-1}, the population size would be (1 person-Sv) + (10 x 10^{-6} Sv); i.e., 100,000 persons for every person-Sv of annual collective dose from *de minimis* sources. However, since doses generally decrease with distance from a given source, the average dose rate amongst those exposed would generally be much less than 10 μSv a^{-1}, and the number of people exposed would have to be correspondingly larger than 100,000 in order to accumulate a person-Sv of annual collective dose. About 30% of these people (i.e., >30,000) would normally (in the absence of the *de minimis* source) die of cancer or suffer a severe genetic defect (2.4).

(c) Radiation Risk Compared With Normal Risk of Cancer and Genetic Defects

In any group of people who receive 1 person-Sv/a from *de minimis* sources, throughout their lifetimes, the number of persons expected to die of cancer or suffer a serious genetic defect is:

- due to the *de minimis* sources, between 0.75 and 7.5 (from (a), above), and
- due to natural and other causes, at least 30,000 (from (b), above).

The fractional increase in risk due to the *de minimis* sources is therefore generally less than about 0.0025% to 0.025% per person-Sv of annual collective dose. This value is consistent with the values that can be calculated using the relationship given by the BEIR committee; namely, that the increase in cancer mortality would be 3 to 8% of the normal incidence if everybody was exposed continuously at the rate of 10 mSv a^{-1} (BE80). Extrapolation from 10 mSv a^{-1} to 10 μSv a^{-1} gives an increased cancer mortality of 0.003 to 0.008% in the exposed population. Any such small fractional increases above the normal incidences of fatal cancer and serious genetic defects would be imperceptible, being completely hidden by the normal fluctuations in the natural incidences of these diseases.

Recommended Value for the Collective *De Minimis* Dose Rate

Since the estimated health risk per person-Sv of annual collective dose is an increase in the incidence of cancer and genetic defects of less than about 0.0025% to 0.025% of the normal incidence of these diseases (from (c), above), which is less than the 0.1% criterion suggested at the start of 7.3, it would appear that one person-Sv/a is a reasonable value for a *de minimis* collective dose rate.

7.4 Summary of *De Minimis* Dose Rates and Associated Health Risks

The *de minimis* dose rates and associated health risks, which are derived in 7.2 and 7.3, are summarized below.

(a) Individual *De Minimis* Dose Rate, 10 μSv a^{-1}

The risk of fatal cancer and serious genetic injury associated with a dose of 10 μSv is less than one in a million. If an individual were to receive 10 μSv every year of his or her life, the expected lifetime health risk therefrom would be in the range of 0.0025% to 0.025% of the normal expectation of these diseases.

(b) Collective *De Minimis* Dose Rate, 1 Person-Sv/a

The estimated number of fatal cancers and serious genetic defects that might result from a collective dose of 1 person-Sv, repeated every year during the lifetimes of the exposed persons, would generally be considerably less than 0.0025% to 0.025% of the normal incidence of these diseases in the exposed population.

(c) Significance of the Health Risks From *De Minimis* Doses

The levels of health risk associated with the foregoing *de minimis* dose rates are generally not considered to be of concern, either by most individuals or by national and international health authorities. Moreover, any resulting increase in the rates of cancer or genetic defects would be imperceptible, being completely hidden by the normal fluctuations in the incidences of these diseases.

8. APPLICATION OF THE *DE MINIMIS* DOSE RATES

8.1 Time Period for Calculating Future Dose Rates

Continual release of long-lived radioactive substances into the environment can lead to an accumulation which can result in higher individual and collective dose rates in the future than at present. In order to allow for such accumulation, while at the same time constraining the calculations to a period for which the future dose rate can be predicted with reasonable confidence, it is recommended for the purposes of this report that the initial calculations of future dose rates be limited to a period of the order of 100 years after the cessation of the practice in question. It is recognized that additional analysis might be indicated in some circumstances.

Despite the uncertainties of predicting future dose rates, the current methods of calculation are sufficiently reliable to give assurance that any effects from a given *de minimis* practice will never be distinguishable from the normal rates of cancer and genetic defects, or from the observable variations in these rates which occur from place to place and time to time.

8.2 Regulatory Considerations

As indicated in Section 3, the Advisory Committees believe that it is important to distinguish between the concepts of *de minimis* and "exempt from regulation". A *de minimis* (or trivial) dose or dose rate is a purely risk-based number and represents a level of risk which is generally accepted as being of no signifi-

cance to an individual or, in the case of a population, of no significance to society. Exemption from regulation relates to a source or a practice, and the decision to exempt involves a number of criteria, among which are:

- the estimated individual dose;
- the probability of exposure of individuals from multiple sources;
- the collective dose;
- justification of the practice.

In this context, the fact that the dose rate from a source or a practice may be below the *de minimis* value would be a major factor, although not the only one, in the decision to exempt that source or practice from regulation. *De minimis* should not be the reason for exemption in cases where there is significant potential for exceeding *de minimis* doses. Conversely, a dose rate above the *de minimis* value would not automatically mean that the source or practice need be regulated.

If more than one *de minimis* source contributes to the dose rate or concentration of radioactive materials in a given location, the net dose rate or concentration could increase above the *de minimis* values. Consideration of such "multiple sources" would be another factor in the decision to exempt the particular sources or practices.

In order to apply the *de minimis* dose rates, it is usually necessary to derive the corresponding quantities or concentrations of specific radioactive substances that could lead to people being exposed at the individual or collective *de minimis* dose rates. Calculation of such "exempt quantities" or "exempt concentrations" involves consideration of exposure pathways, critical groups and other factors that are beyond the scope of this report.

9. RECOMMENDATIONS

It is recommended that:

(i) the AECB adopt the concept of *de minimis* dose rate as a practical basis for exempting specific sources and practices from licensing, the recommended values being:

- for individuals, 10 μSv a^{-1}, and
- for populations, 1 person-Sv a^{-1};

These *de minimis* values would normally apply to the maximum annual dose rates estimated to occur within a period of the order of 100 years after the cessation of any given practice.

(ii) criteria and guidelines be developed for deriving quantities and concentrations of specific radioactive substances that may be "exempted from regulatory control", taking into account the *de minimis* dose rates and the relevant exposure pathways and other factors involved.

Table 1

ESTIMATES OF THE POTENTIAL LIFETIME RISKS OF RADIATION-INDUCED FATAL CANCERS AND SERIOUS GENETIC DEFECTS (per 100 Sv)

	UN88 (1)	BEIR-V (2)	ICRP 90 (3)
Fatal Cancers in the Total Population at Low Dose Rates	0.4 - 5.5 (a)	2.3 - 4.4 (c)	5.0 (e)
Serious Genetic Defects To all Generations at Low Dose Rates	0 - 2 (b)	1.1 - 2.0 (d)	1.0 (e)
Total (Cancer plus Genetic)	0.4 - 7.5	3.4 - 6.5	6.0

(1) UN88, UNSCEAR 1988, "Sources, Effects and Risks of Ionizing Radiation", United Nations Scientific Committee on the Effects of Atomic Radiation", Report to the General Assembly, with Annexes, United Nations, New York 1988.

(2) BE90, BEIR-V 1990, "Health Effects of Exposure to Low Levels of Ionizing Radiation", Committee on the Biological Effects of Ionizing Radiations, National Academy of Sciences, Washington, D.C., 1990.

(3) IC90, ICRP 90/G-01, "Recommendations of the International Commission on Radiological Protection", ICRP, Draft, February 1990.

(a) Derived from Table 10, page 39 of UN88 using a DREF* of 2-10 as recommended in paragraph 249.

(b) Taken from Table 8 of UN88 on page 38.

(c) Derived from Table 4.2 of BE90 on page 172 using a DREF of 2 to 5 for solid cancers as recommended in Table 1-4 of BE90 on page 23.

(d) Derived from Table 2-1 of BE90 on page 70.

(e) Taken from Table 3 of IC90 on page 3-13. A DDREF** of 2 was used to obtain these risk coefficients.

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* Dose Rate Effectiveness Factor: a factor used to derive risk estimates of exposure to low-LET radiation at low dose rates, from risk estimates calculated from data associated with exposures at high dose rates.

** Dose and Dose Rate Effectiveness Factor: a factor used to derive risk estimates of low doses of low-LET radiation at low dose rates, from risk estimates calculated from data associated with large doses at high dose rates.

Table 2

REGULATORY DOSE LIMITS

(a) CURRENT LIMITS (AE88)

Organ or Tissue	Maximum Permissible Doses*		
	For Atomic Radiation Workers		For Any Other Person
	mSv per quarter of a year	mSv per year	mSv per year
Whole body, gonads, bone marrow	30	50	5
Bone, skin, thyroid	150	300	30
Any tissue of hands, forearms, feet and ankles	380	750	75
Lungs and other single organs or tissues	80	150	15

* These limits apply to the total dose from sources of ionizing radiation both inside and outside the body, and are based on ICRP-9 (IC65). The limits are expressed in rems in the AEC Regulations, and the corresponding values given here in mSv were derived by multiplying the values in rems by ten.

Table 2 (continued)

(a) CURRENT LIMITS (continued)

Maximum Permissible Exposures To Radon Daughters These exposure limits apply instead of the maximum permissible doses for the lungs tabulated above.		
For Atomic Radiation Workers		For Any Other Person
WLM* per quarter of a year	WLM per year	WLM per year**
2	4	0.4

* The working level month (WLM) and working level (WL) are defined in the glossary.

** The WLM unit is not appropriate for exposures in the home or in other non-occupational situations. In such situations, the maximum permissible annual average concentration of radon daughters attributable to the operation of a nuclear facility is 0.02 WL.

(b) PROPOSED LIMITS (AE86)

	Effective Dose Equivalent* mSv	Dose Equivalent to Individual Organs and Tissues mSv	
		Eye Lens	Others
For Atomic Radiation Workers per quarter of a year per year	30 50	80 150	300 500
For Other Persons per year	5	50	50

* The EDE concept was introduced by the ICRP in 1977 (IC77a) and is included in AECB Consultative Document C-83 (AE86). The reasons for introducing EDE are given in AE83.

Table 3

SUMMARY OF ANNUAL PER CAPUT RADIATION DOSES FROM NATURAL SOURCES

(Effective Dose Equivalent, $\mu Sv\ a^{-1}$)

Source	External	Internal	Total
Cosmic radiation	$270^{(1)}$-$355^{(2)}$		$270^{(1)}$-$355^{(2)}$
Radionuclides produced naturally in the atmosphere (mainly carbon-14 and beryllium-7)		$10^{(1)}$-$15^{(2)}$	$10^{(1)}$-$15^{(2)}$
Radionuclides in the earth's crust (excluding radon and thoron decay products)	$280^{(1)}$-$410^{(2)}$	$340^{(2)}$-$390^{(3)}$	$670^{(3)}$-$750^{(2)}$
radon decay products		$1100^{(2)}$-$1920^{(3)}$	$1260^{(2,4)}$-$2000^{(3,4)}$
thoron decay products		$32^{(3)}$-$160^{(2)}$	
Rounded total			$2400^{(2)}$-$3000^{(1)}$

(1) National Council on Radiation Protection and Measurements (NC87c)

(2) United Nations Scientific Committee on the Effects of Atomic Radiation (UN88)

(3) National Council on Radiation Protection and Measurements (NC87b)

(4) Total of both radon and thoron decay products

Table 3 (continued)

SUMMARY OF RADIATION DOSES FROM MAN-MADE SOURCES

(Effective Dose Equivalent, $\mu Sv\ a^{-1}$)

Source	Dose	References
Diagnostic medicine (diagnostic radiology and nuclear medicine combined)	540 400 - 1000 2000	NC89 UN88 LE88
one chest x-ray	70 - 80	UN88, NC89
Fallout from weapons testing	10	NC87A
Strontium-90 and Cesium-137 in Canadian Milk	0.2 - 1	HW85
Consumer products (not including drinking water and building materials which are accounted for in natural sources)	10	NC87b
Nuclear Fuel Cycle Carbon-14 and tritium	<1	NC87
Nuclear power plants in Ontario (critical group)	2 - 50	OH88
Coal-fired power plants (critical group)	2 - 40	UN88

Table 4

EXTERNAL BACKGROUND DOSE IN VARIOUS LOCATIONS ACROSS CANADA

LOCATION		
Cities	Near Nuclear Power Plants	μSv Per Year*
Calgary, Montreal, Toronto, Vancouver		400-450
	Pickering, Ontario	430
	Gentilly, Quebec	430
	Point Lepreau, N.B.	440
	Bruce, Ontario	460
Inuvik, Ottawa, Quebec, Thunder Bay, Winnipeg, Windsor		460-480
Fredericton, Halifax, Regina, Saskatoon		500-560
Edmonton, St. John's, Whitehorse, Yellowknife		570-640

* average values (HW85)

Table 5

CROSS-CANADA CONCENTRATIONS OF RADON PROGENY IN HOMES AND RESULTING DOSES

LOCATIONS (cities within groups are listed in order of increasing concentration)	Average Concentrations of Radon Progeny in Homes in Canadian Cities, and Corresponding Doses Due to Inhalation	
	Concentration* Working Levels	EDE** μSv per year
Vancouver	0.0012	300
Charlottetown, Toronto, St. John's (Nfld), Montreal, Quebec	0.0021 to 0.0028	500 to 600
Sherbrooke (PQ), Edmonton, Thunder Bay, St. John (NB), Calgary	0.0031 to 0.0047	700 to 1100
Regina, Sudbury, Halifax, St. Lawrence (Nfld), Fredericton, Saskatoon	0.0052 to 0.0078	1200 to 1800
Winnipeg	0.011	2500
Homes in uranium mining communities:		
Bancroft	0.013	3000
Elliot Lake	0.014	3200
Uranium City	0.036	8300

* Arithmetic mean concentrations calculated from geometric means given in (Le84).

** Assuming 5500 μSv of effective dose equivalent per working level month (NE83) and that people spend 80% of their time in their homes.

Table 6

CANCER DEATH RATES IN CANADA
deaths per year per 100,000 of Canadian population*

a) Variation by Sex

average for all ages and all of Canada:
males - 186 cancer deaths per 100,000
females - 147 " " " "

b) Variation by Province

average for all ages and both sexes:
from 121 cancer deaths per 100,000 (in Alberta)
to 190 " " " " (in Manitoba)

c) Variation by Age

average for both sexes and all of Canada:

Age Range	Cancer Deaths per 100,000	Age Range	Cancer Deaths per 100,000
0-24	5	55-59	343
25-29	9	60-64	509
30-34	15	65-69	715
35-39	31	70-74	960
40-44	61	75-79	1221
45-49	114	80-84	1589
50-54	204	85 and older	1842

* Source: sample values selected from extensive tables in "Cancer in Canada", 1981 (SC86)

Table 7

EXAMPLES OF ONE-IN-A-MILLION RISKS (Activities Which have been Calculated to Increase Risk of Death by One in a Million)
Smoking 1.4 cigarettes*
Drinking 1/2 litre of wine*
Eating 100 charcoal-broiled steaks*
Living 2 months with a cigarette smoker*
One chest radiograph using modern equipment*
Travelling 6 minutes by canoe*
Travelling 10 miles by bicycle*
Travelling 50 miles by car*
Flying 1000 miles by jet (risk of crash rather than of increased exposure to radiation)*
Rock climbing 1½ minutes+
Alpine skiing 60 minutes+
Working 24 hours in the chemical industry+
Working 13 hours in the construction industry+
Working 9½ hours as a coal miner+

* (Wi79)
\+ (RS83)

Note: The *de minimis* dose rate per year recommended in this report will result in a risk of less than one in a million.

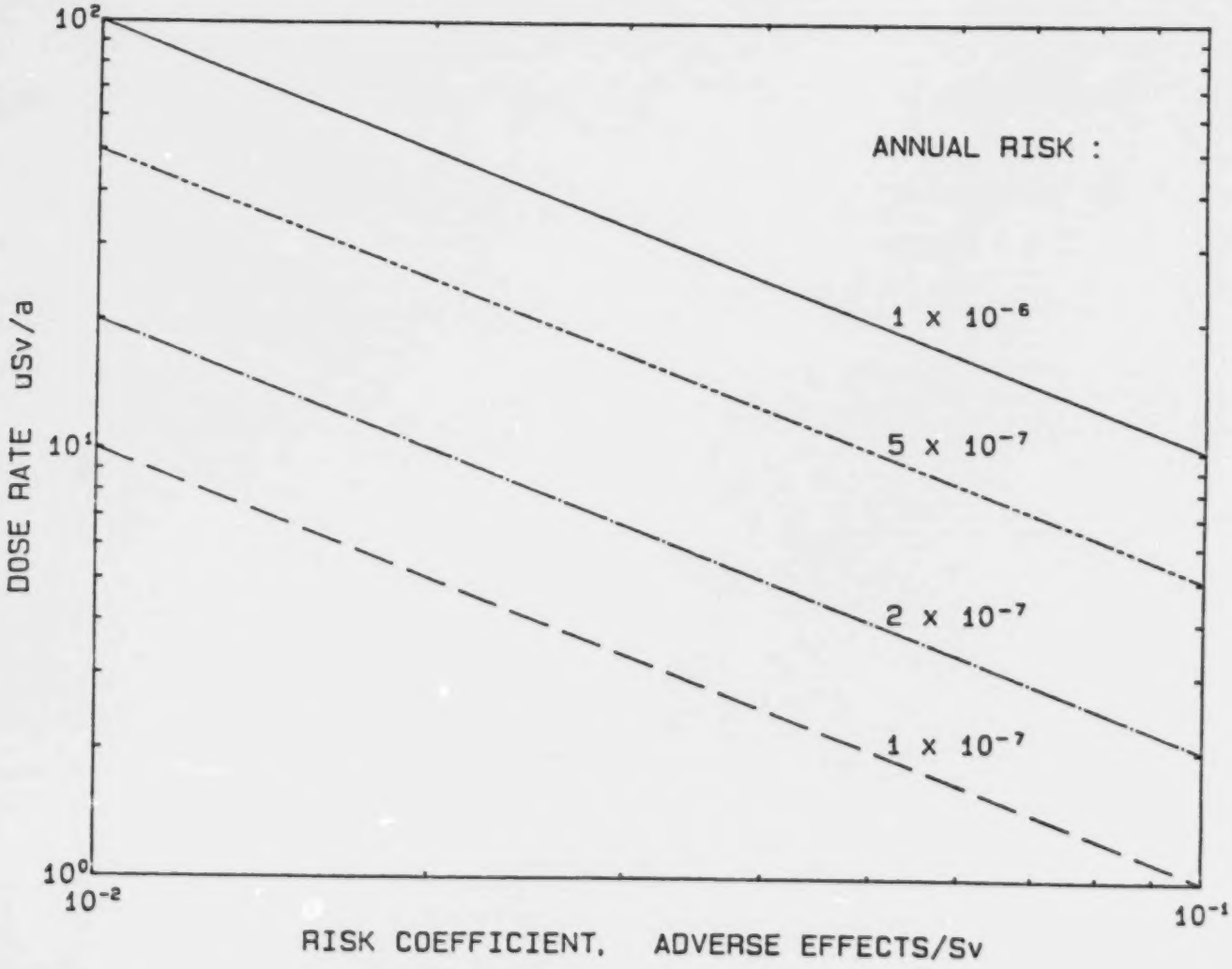

Figure 1: *De Minimis* Dose Rates as a Function of Risk Coefficient

GLOSSARY

"a": year(annum); "/a": per year;

"ACNS": Advisory Committee on Nuclear Safety;

"ACRP": Advisory Committee on Radiological Protection;

"AECB": Atomic Energy Control Board;

"Advisory Committee on Nuclear Safety" (ACNS): a committee of scientists and engineers appointed by the AECB to provide independent advice on any matter related to nuclear safety;

"Advisory Committee on Radiological Protection" (ACRP): a committee of scientists and medical or radiation protection experts appointed by the AECB to provide independent advice on any matter relating to "radiation protection";

"ALARA": a principle of radiation protection according to which radiation doses are kept as low as reasonably achievable, economic and social factors being taken into account;

"Atomic Energy Control Act": an act passed by Parliament in 1946 in order to provide for the control and supervision of the development, application and use of atomic energy and to enable Canada to participate effectively in measures of international control of atomic energy;

"Atomic Energy Control Board" (AECB): a body corporate constituted by the Atomic Energy Control Act for the purposes set out in the Act;

"Atomic Energy Control Regulations": regulations made pursuant to the Atomic Energy Control Act by the Atomic Energy Control Board;

"Atomic Radiation Worker": any person who, as an essential requirement of his or her work, could in the course of that work receive a dose of radiation greater than any limit specified for "any other person" in Table 2;

"BEIR": Committee on the Biological Effects of Ionizing Radiations;

"below regulatory concern": as used in this report, refers to a source or practice which is exempted from regulation;

"collective dose": the sum of the individual doses received by all the persons exposed to a given source of radiation; it is also the product of the average dose to a group of exposed persons and the number of persons in the group; collective dose is generally expressed in "person-Sv";

"committed dose": the total dose received from radioactive substances in the body during the 50 years following the intake of those substances;

"critical group": a fairly homogeneous group of people whose location, age, habits, diet, etc., cause them to receive an average dose from a given source (or a given combination of sources) of radiation which is greater than the average dose received by any other group exposed to that source or combination of sources;

"*de minimis* dose or dose rates": as used in this report, represents a level of risk which is generally accepted as being of no significance to an individual, or in the case of a population, of no significance to society;

"detriment": the mathematical expectation of harm due to exposure to radiation, taking into account the probability and the severity of each type of deleterious effect;

"disease": a condition of the body that impairs the performance of a vital function;

"dose": a dose of radiation, either "dose equivalent", "committed dose equivalent", "effective dose equivalent", or "committed effective dose equivalent", depending on the context;

"dose commitment": the infinite time integral of the per caput dose rate for a specified population; in other words, the total dose that would be accumulated by an immortal person if exposed to the given source until its complete radioactive decay;

"dose equivalent": the "absorbed dose" multiplied by a "quality factor" to account for the different potential for injury of different types of radiation, where the "absorbed dose" is the amount of energy absorbed in the body, or in an organ or tissue of the body, due to exposure to ionizing radiation, divided by the respective mass of the body, organ or tissue; the unit of absorbed dose is the joule per kilogram and its special name is the gray (Gy); 1 Gy = 1 joule/kg (= 100 rads); a "gray" of absorbed dose multiplied by the appropriate quality factor yields "sieverts" of dose equivalent;

"dose rate": dose per unit of time;

"DREF": Dose Rate Effectiveness Factor: a factor used to derive risk estimates of exposure to low-LET radiation at low dose rates, from risk estimates calculated from data associated with exposures at high dose rates.

"DDREF": Dose and Dose Rate Effectiveness Factor: a factor used to derive risk estimates of low doses of low-LET radiation at low dose rates, from risk estimates calculated from data associated with large doses at high dose rates.

"EDE": effective dose equivalent;

"effective dose equivalent": the sum of the "weighted dose equivalents" received by the organs and tissues of the body, where the weighted dose equivalent is the dose equivalent to an organ or tissue multiplied by a "weighting factor" to account for the risk of fatal cancer or inheritable injury resulting from irradiation of the given organ or tissue compared to the total risk of such effects resulting from the receipt of an equal dose equivalent by the whole body;

"exempt source or practice": a source of radiation or a practice that is exempted from regulation by the regulatory authorities;

"external exposure": exposure to an "external source" of radiation; that is, to a source that is outside the body;

"genetic effects": inheritable (hereditary) defects that are genetically transmitted from a parent to a child and which may appear amongst the children and subsequent generations of a parent whose gonads (ovaries or testes) have been exposed to radiation anytime before the conception of children;

"gonads": the testes in a male and the ovaries in a female;

"ICRP": International Commission on Radiological Protection;

"internal exposure": exposure to an "internal source" of radiation; i.e., exposure due to a radioactive substance inside the body;

"ionizing radiation": see "radiation":

"LET": Linear Energy Transfer, i.e., the energy transferred to a substance as a neutron, a charged particle or a photon interacts with electrons in traversing a given distance through the substance;

"low-LET radiation": radiation of low Linear Energy Transfer, which includes X-, beta and gamma radiation, (high-LET radiations include neutrons and alpha particles);

"microsievert" (μSv): one millionth of a sievert;

"millisievert" (mSv): one thousandth of a sievert;

"objective health detriment": the part of the total detriment that is proportional to the effective dose equivalent; i.e., excluding subjective valuations, such as anxiety, which depend on the dose level;

"person-sievert": the unit of "collective dose";

"person-Sv": person-sievert;

"quality factor": see the definition of "dose equivalent";

"radiation": ionizing radiation; i.e., any atomic or subatomic particle or electromagnetic wave having sufficient energy per particle or photon to produce ions (atoms which have become charged due to the loss or gain of electrons) in the material in which it is absorbed; ionizing radiation includes alpha and beta particles, X-rays and gamma radiation, neutrons, and some other charged particles;

"radiation protection" (also radiological protection): the science and practice of assessing radiation hazards and developing, encouraging the use of, and using instruments, protective clothing, guidelines and procedures required for keeping radiation doses within the dose limits and as low as reasonably achievable;

"radioactive": exhibiting radioactivity, which is the property of undergoing a spontaneous nuclear transformation with the emission of ionizing radiation;

"radon" (Rn-222): the radioactive gas produced by the radioactive decay of radium-226 (which is produced through a series of radioactive decay steps from uranium-238), and which, through radioactive decay, gives rise to "radon daughters";

"radon daughters" (Rn-222 daughters): the following short-lived radioactive substances produced by a series of radioactive disintegrations starting with the disintegration of radon-222: polonium-218 (radium A), lead-214 (radium B), bismuth-214 (radium C), and polonium-214 (radium C');

"risk coefficient": equivalent to "risk factor" (see below);

"risk factor": as used in this report, the probability of fatal cancer or serious genetic defects per unit of radiation dose;

"sievert" (Sv): the special name of the unit of "dose equivalent" and of "effective dose equivalent" (1 Sv = 1000 mSv = 1,000,000 μSv); the sievert is defined earlier under "dose equivalent"; (the name of the old unit of dose equivalent is the rem, which equals 0.01 Sv);

"source": a source of radiation, or a practice giving rise to radiation;

"Sv": sievert;

"thoron" (Rn-220): the radioactive gas produced by the radioactive decay of radium-224 (which is produced through a series of radioactive decay steps from thorium-232), and which, through radioactive decay, gives rise to "thoron daughters";

"thoron daughters" (Rn-220 daughters): the following short-lived radioactive substances produced by a series of radioactive disintegrations starting with the disintegration of radon-220: polonium-216 (thorium A), lead-212 (thorium B), bismuth-212 (thorium C) and polonium-212 (thorium C');

"UNSCEAR": United Nations Scientific Committee on the Effects of Atomic Radiation;

"working level" (WL): a unit of concentration of radon or thoron daughters in air expressed in terms of the potential alpha energy of the amount of daughters in a cubic metre or a litre of air; 1 WL = 2.08×10^{-5} joule per cubic metre = 1.3×10^{5} MeV per litre; (the "potential alpha energy" is the energy of all the alpha particles that could be released from a given quantity of radon or thoron daughters during their successive stages of radioactive decay to lead-210 and lead-208 respectively);

"working level month" (WLM): 170 working level hours.

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